Balanced Upper Ocean Variability in the 15-150km Wavelength Range

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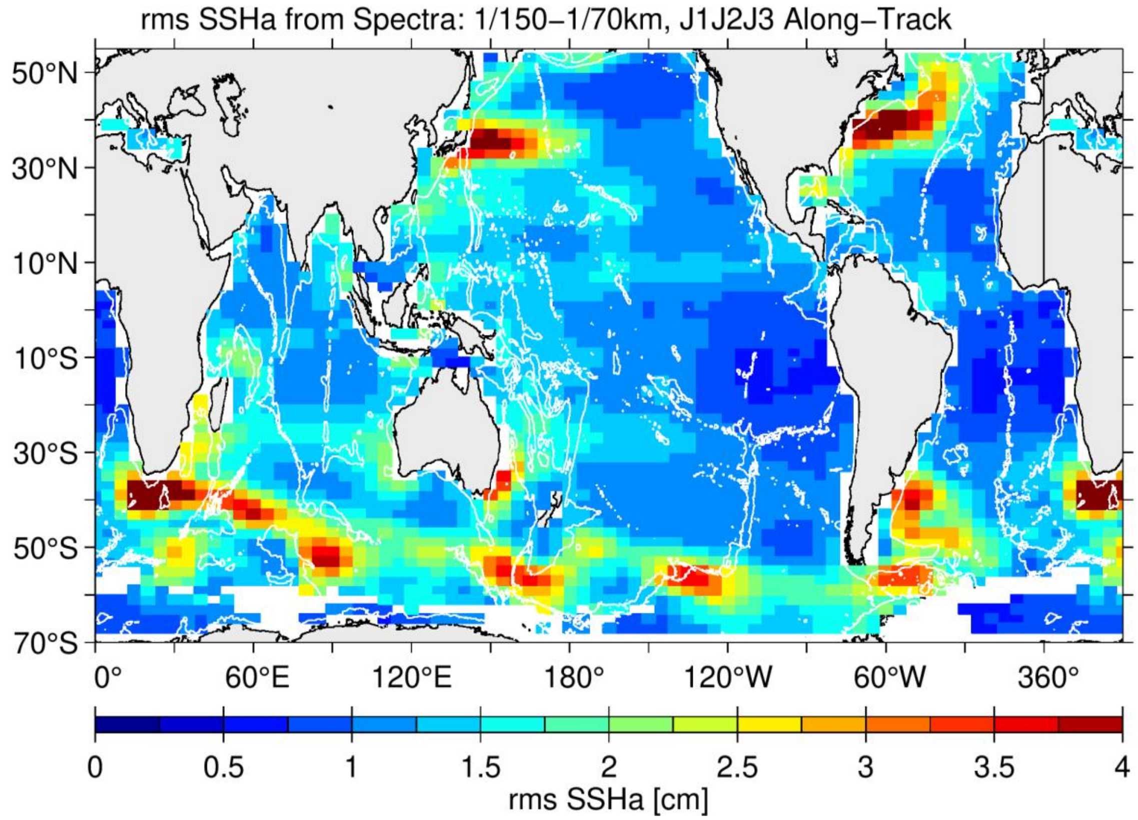
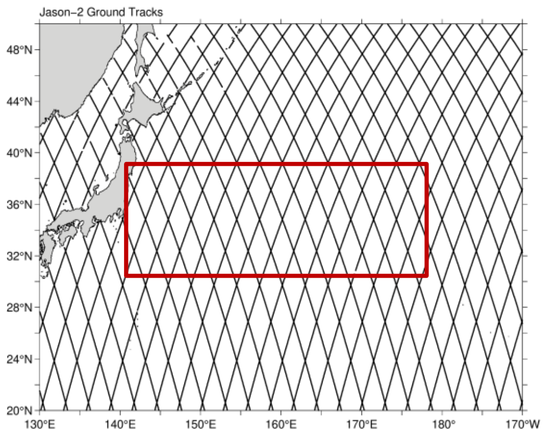


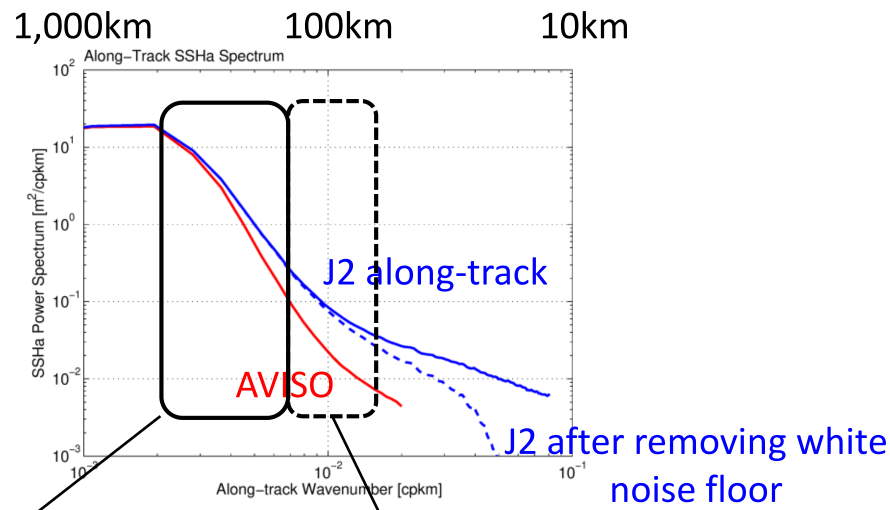
OSTST Science Team Meeting, Online, 19-23 October 2020

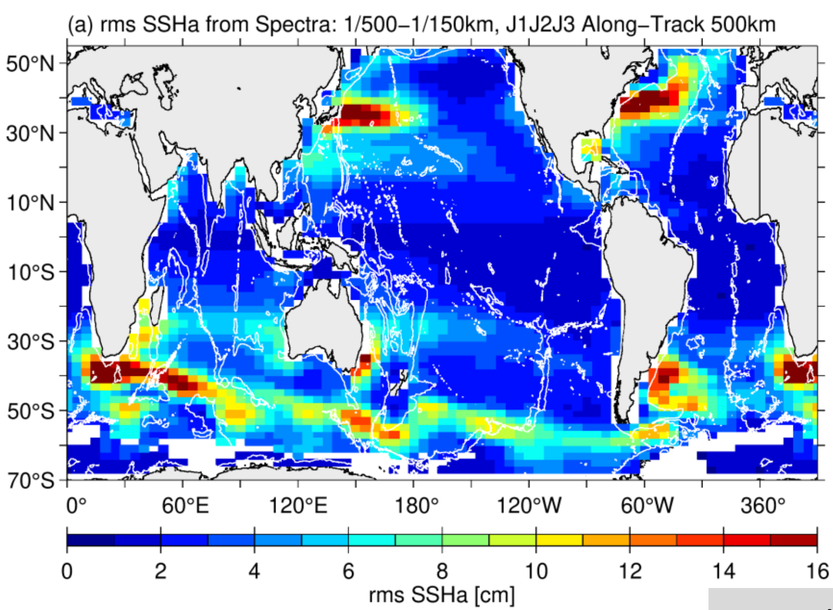
Background:

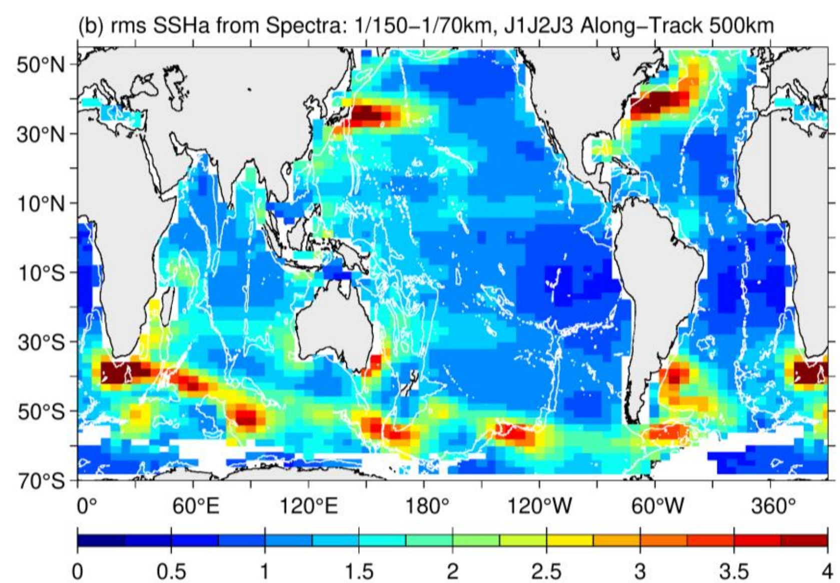
- The global, multi-mission-merged, AVISO SSH product has become a backbone for the past mesoscale oceanic variability research.
- Due to the need for spatial uniformity, the effective horizontal resolution of the AVISO gridded product is O(150–200km) (e.g., Chelton et al. 2011; Ballarrotta et al. 2019).
- With the reprocessing of along-track altimeter data, we have now improved fine-scale along-track SSH data with lower noise levels (Morrow et al. 2018).
- During the next OSTST, we will also have the wide-swath 2-D SSH data from the SWOT mission that will improve the measured SSH resolution down to O(15km).
- In this presentation, I'll provide a brief review on:
  1. What dynamic signals are at the 15~150km wavelengths? Are they geostrophically balanced?
  2. Dynamic relevance of the fine-scale SSH signals: EKE pathways
  3. Importance to the upper ocean vertical circulation/transport

J2-along-track vs. AVISO-gridded SSH power spectrum comparison



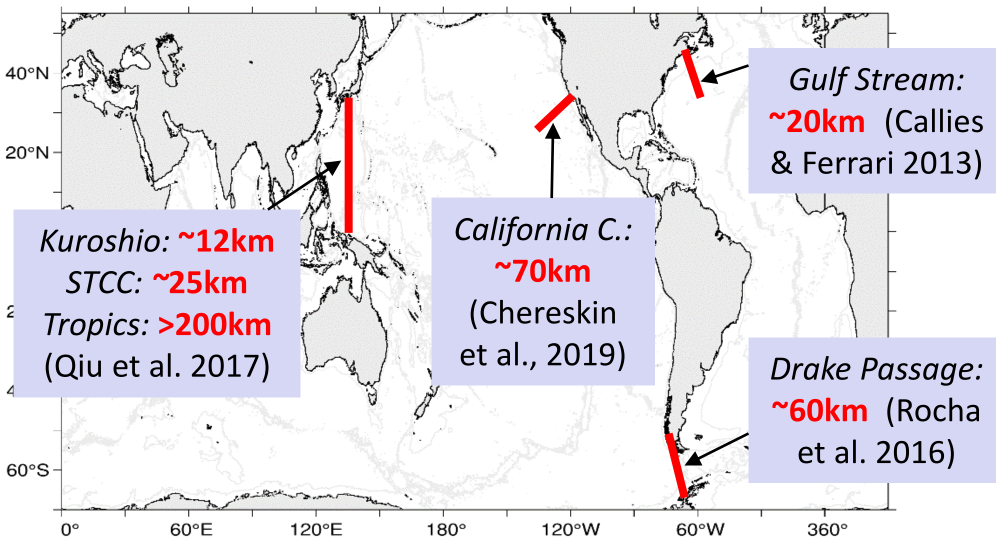






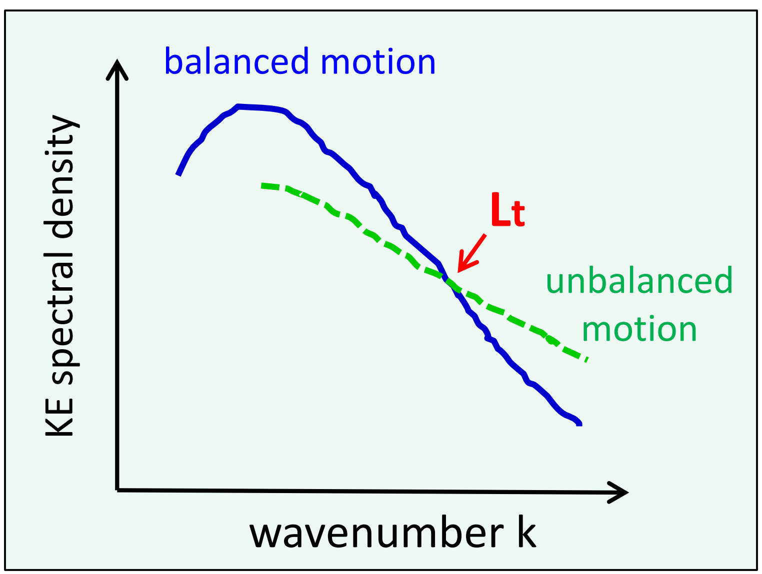
Are these fine-scale SSH signals geostrophically balanced?

Are SSH signals in sub-150km range geostrophically balanced?



- Several studies have used repeat ADCP surveys to determine the transition scale: **Lt**

- **Lt** is spatially inhomogeneous; smaller at where regional mesoscale EKE level is high



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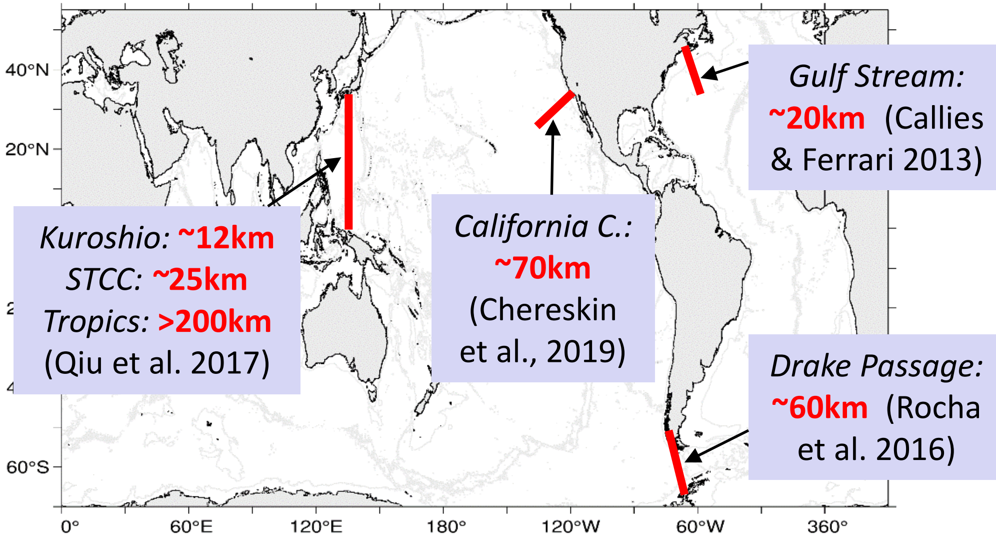
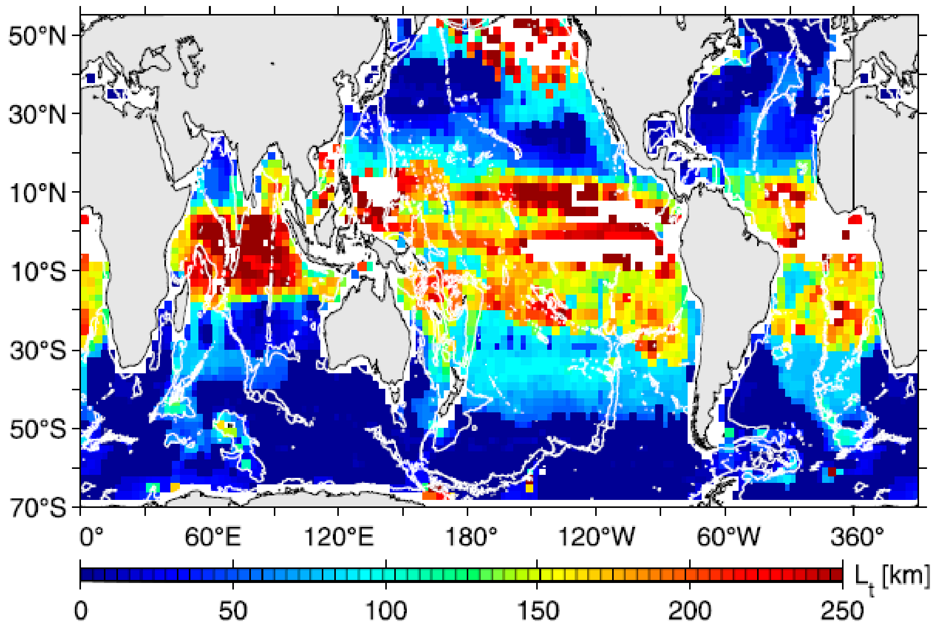




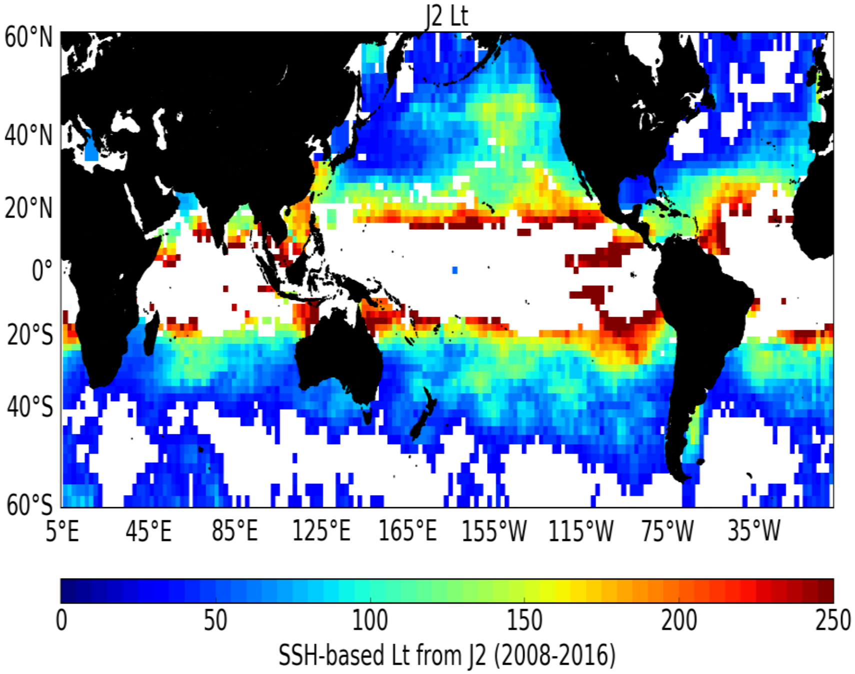
MITgcm-based **Lt** (Qiu et al. 2018)

- Several studies have used repeat ADCP surveys to determine the transition scale: **Lt**

- **Lt** is spatially inhomogeneous; smaller at where regional mesoscale EKE level is high

- **Lt** was also evaluated globally using the 1/48° MITgcm simulation that includes tidal forcing

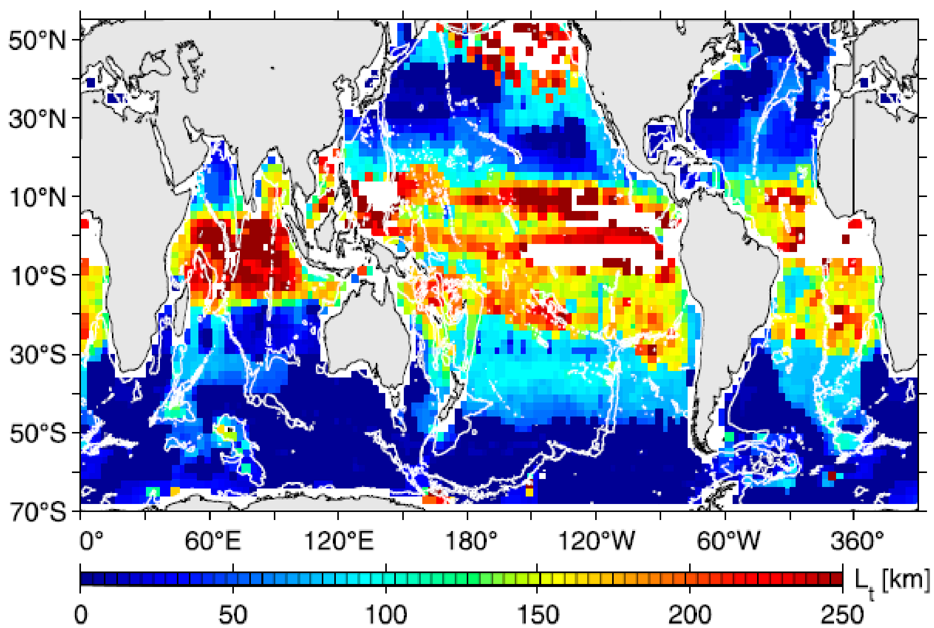
- **Lt < 30km** in WBC & ACC regions; exceptions appear in EAC & in ACC areas with prominent topographic features
- In temperate latitudes (i.e., STCC bands), **Lt = 50~100km**
- **Lt > 150km** in broad tropics



J2-alongtrack-SSH-based **Lt**
(Vergara et al. 2020)

- **Lt** is recently evaluated globally using the J2/AL along-track SSH data based on spectral slope breaks between balanced vs. unbalanced motions

- Global **Lt** pattern is largely consistent with the MITgcm estimates
- In WBC & ACC regions, altimeter-based **Lt** is **~ 50km**, slightly larger than MITgcm; this may be limited by the along-track SSH resolution

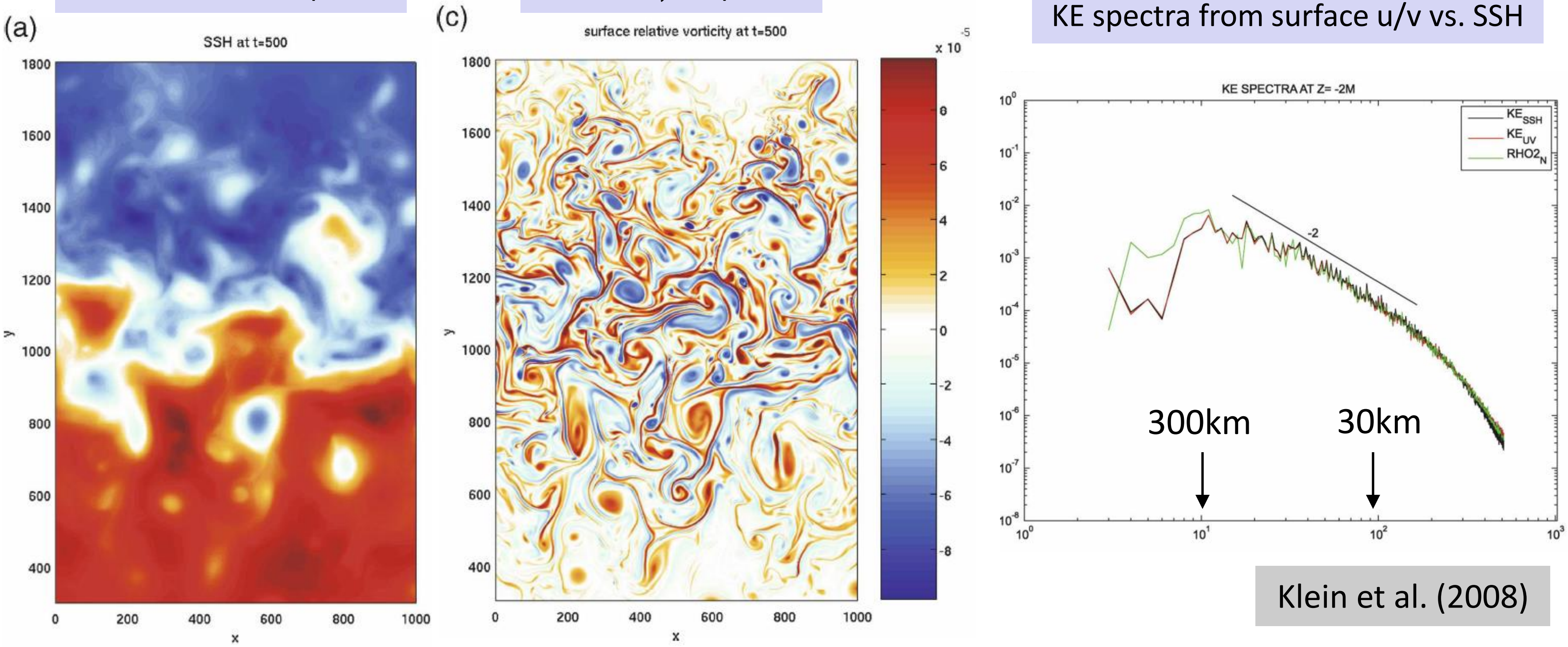


MITgcm-based **Lt** (Qiu et al. 2018)

Modeled SSH snapshot

Surface ζ snapshot

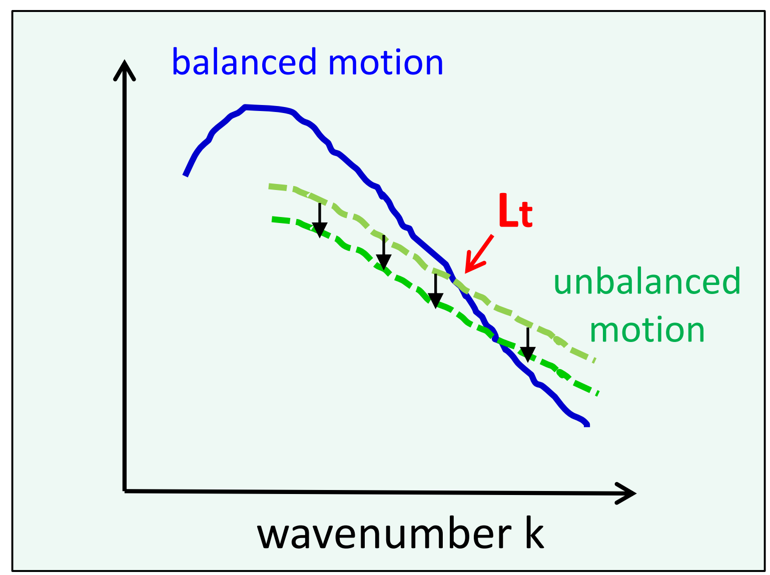
KE spectra from surface u/v vs. SSH



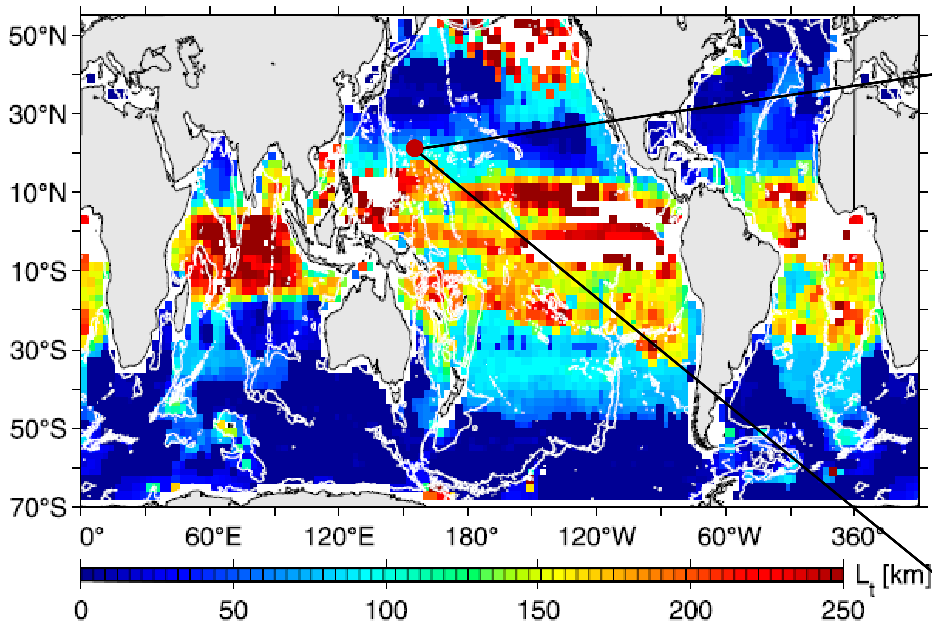
Klein et al. (2008)

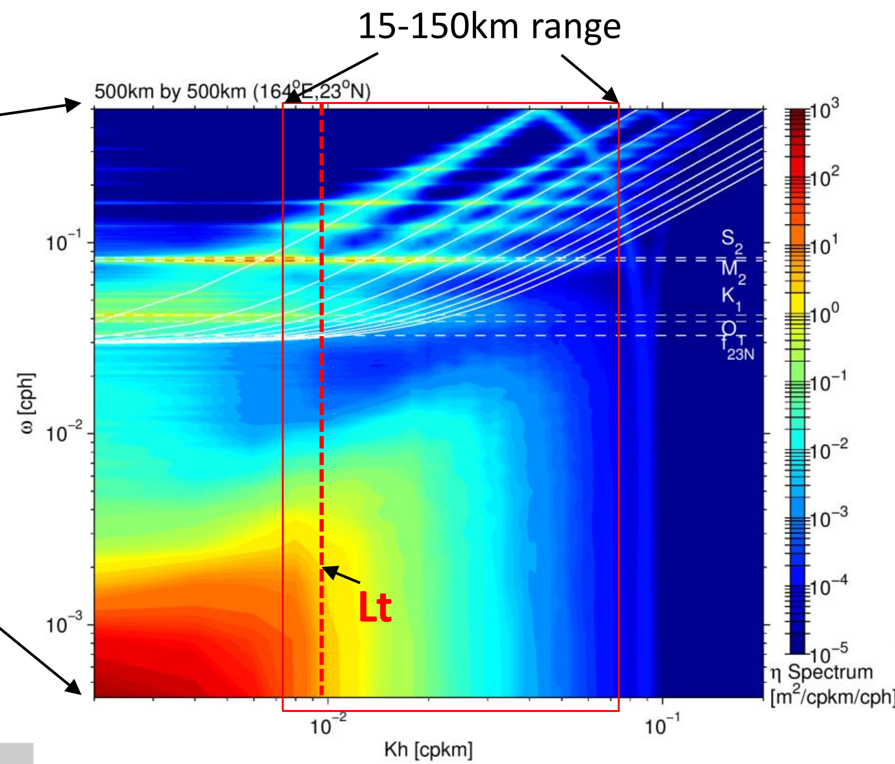
- In an idealized 2km-resolution OGCM simulation (no tides; re-entrant baroclinic zonal jet), geostrophic balance is found to be valid down to O(10km)

- Implication: If we're able to delineate SSH signals due to the unbalanced wave motions, we could detect balanced motions from SSH shorter than **Lt**



What constitutes the unbalanced motions in 15–150km range ?



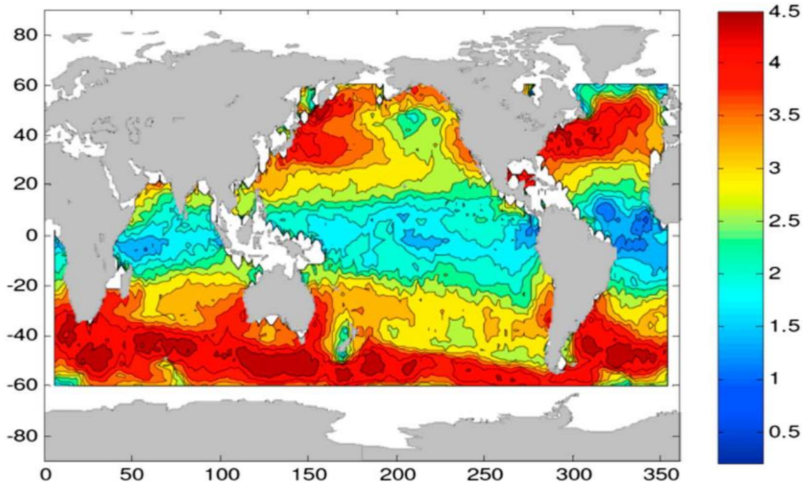


- In the 15-150km range, unbalanced motions are dominated by semi-diurnal internal tides + mode-1~3 IGWs

Typical SSH wavenumber-frequency spectra from MITgcm in a STCC region; **Lt ≈ 100km** in this example.

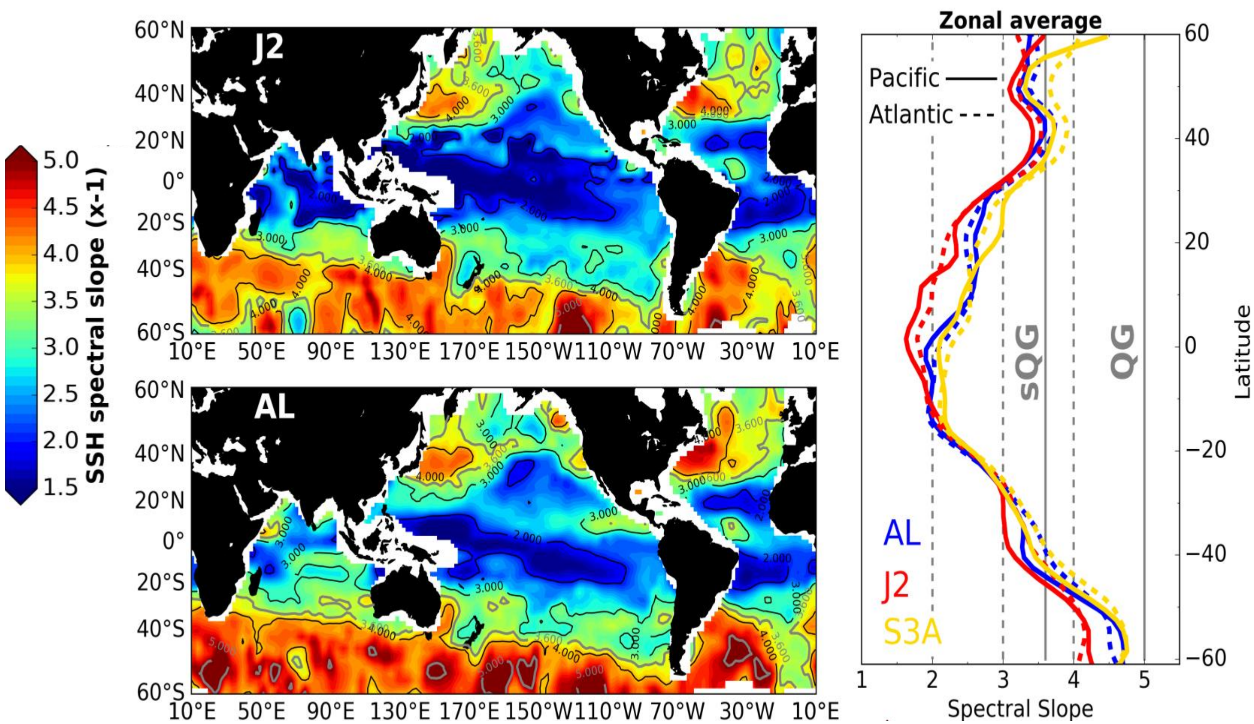
- Reduction of these wave motion signals will allow us to examine, in this case, balanced, sub-inertial, fine-scale motions in the sub-100km range

Exploring governing dynamics from SSH spectral slopes



Xu & Fu (2012)

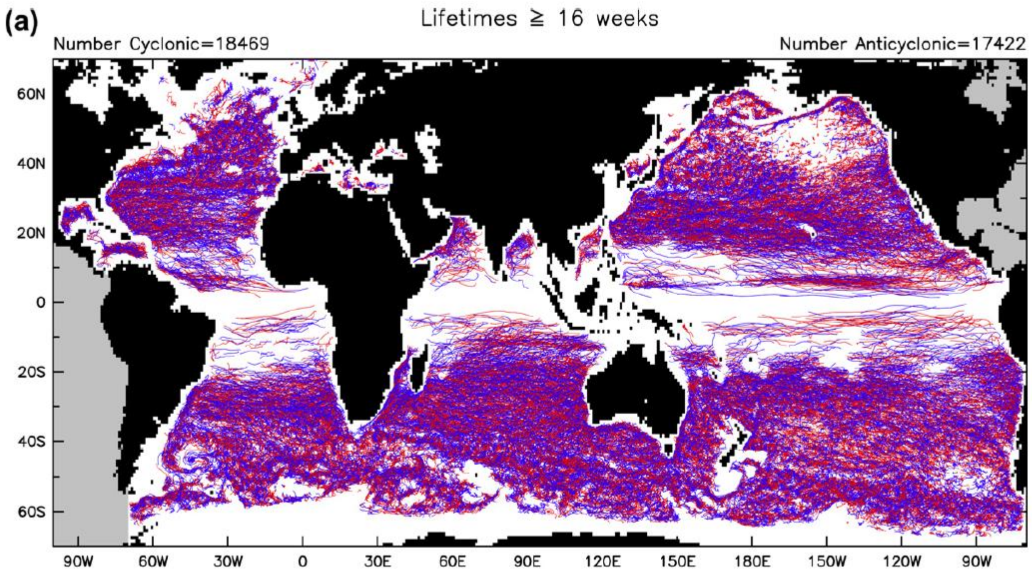
- De-noised alongtrack SSH spectral slopes have been used to infer the governing dynamics, QG vs. SQG, or Phillips- vs. Charney-type instability
- Consistent results emerged, despite different slope fitting methodologies



- WBCs are more SQG than QG (also Le Traon et al. 2008)
- ACC is an admixture of SQG & QG
- Tropics are dominated by waves (~k^{-2}), consistent with the **Lt** estimate

Vergara et al. (2019)

Impact of mesoscale eddies upon finer-scale motions

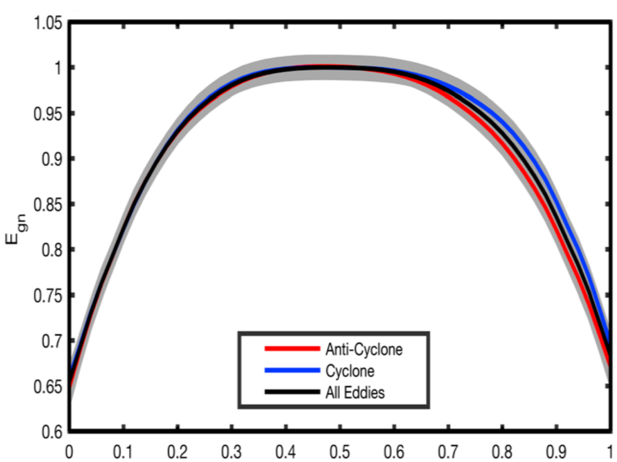


Chelton et al. (2011)

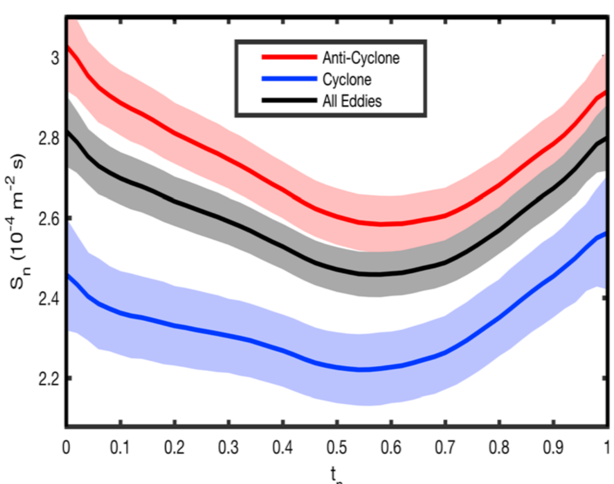
- Combined Chelton's eddy-tracking dataset & global surface drifter data to explore mesoscale eddy's impact on finer-scale features via composites

- While no differences are found in EKE levels between AEs & CEs, AE's strain levels (evaluated from AVISO-SSH) are ~30% higher than those of CEs.

Normalized mesoscale EKE as a function of eddy life-cycle



Normalized mesoscale strain S_g as a function of eddy life-cycle

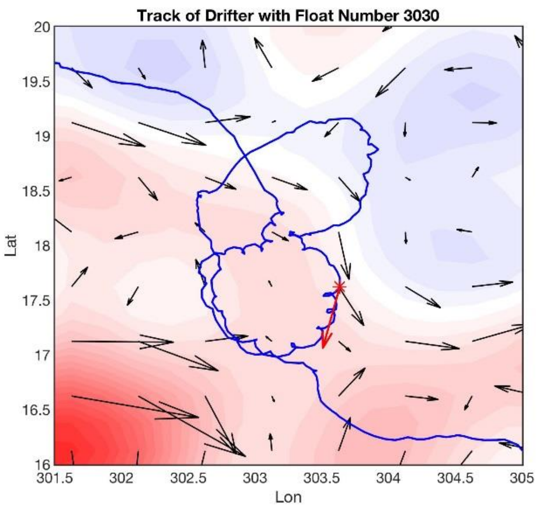


$$S_g = \sqrt{\left(\frac{\partial u_g}{\partial x} - \frac{\partial v_g}{\partial y}\right)^2 + \left(\frac{\partial v_g}{\partial x} + \frac{\partial u_g}{\partial y}\right)^2}$$

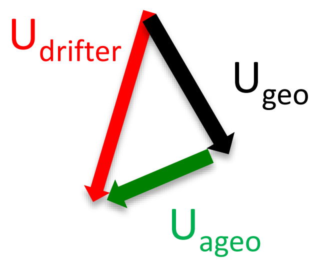
(statistics based on 215K tracked eddies)

Zhang & Qiu (2018)

Impact of mesoscale eddies upon finer-scale motions



AVISO-SSH map in color

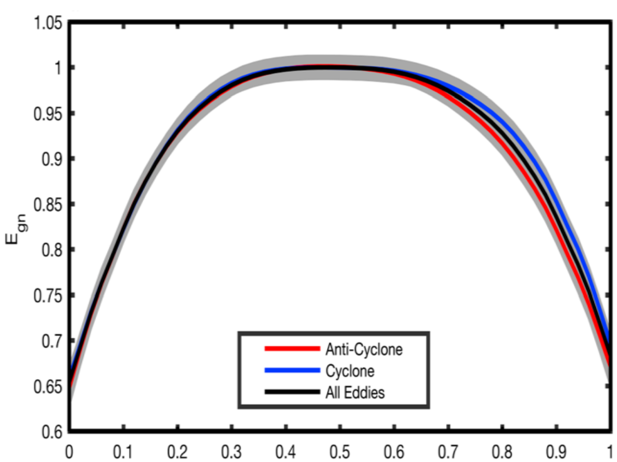


- From concurrent AVISO-SSH & surface drifter velocity data, evaluated ageostrophic flows U_{ageo} as residue

- Using scale separation, removed mesoscale U_{ageo} induced by the cyclostrophic effect

- Consistent with the strain signals, AEs are found to have higher, fine-scale $\langle U_{ageo}^2 \rangle$ levels than CEs

Normalized mesoscale EKE as a function of eddy life-cycle



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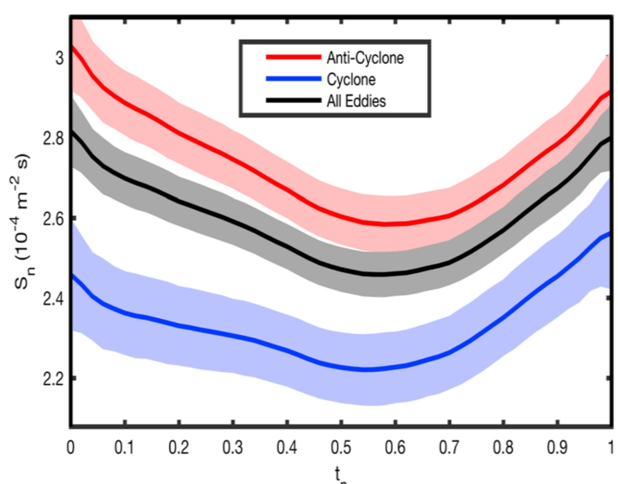
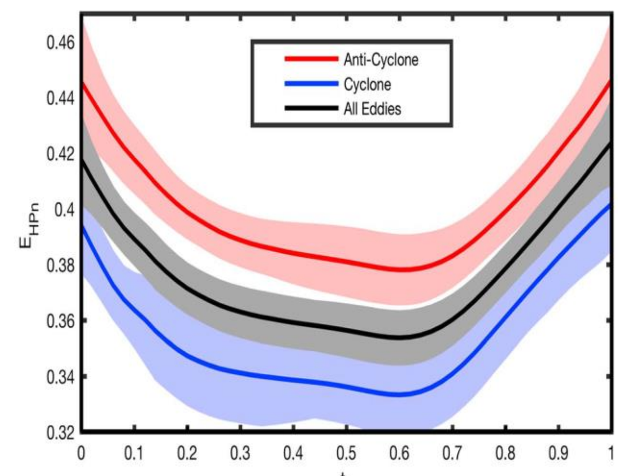


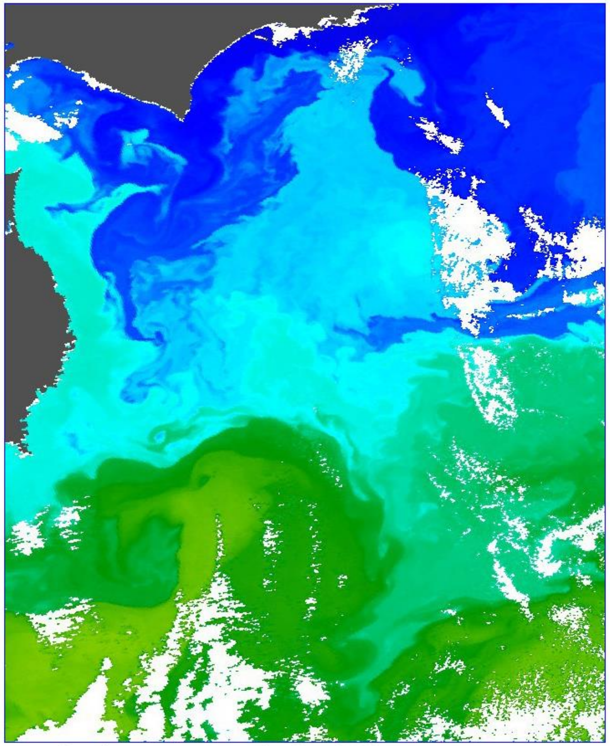
Normalized fine-scale EKE as a function of eddy life-cycle



(statistics based on 215K tracked eddies)

(statistics based on 22M collocated drifter/eddy obs.)

Typical SST maps surrounding an AE east of Japan



2007/02/22 03:00 Aqua/MODIS SST

Comments

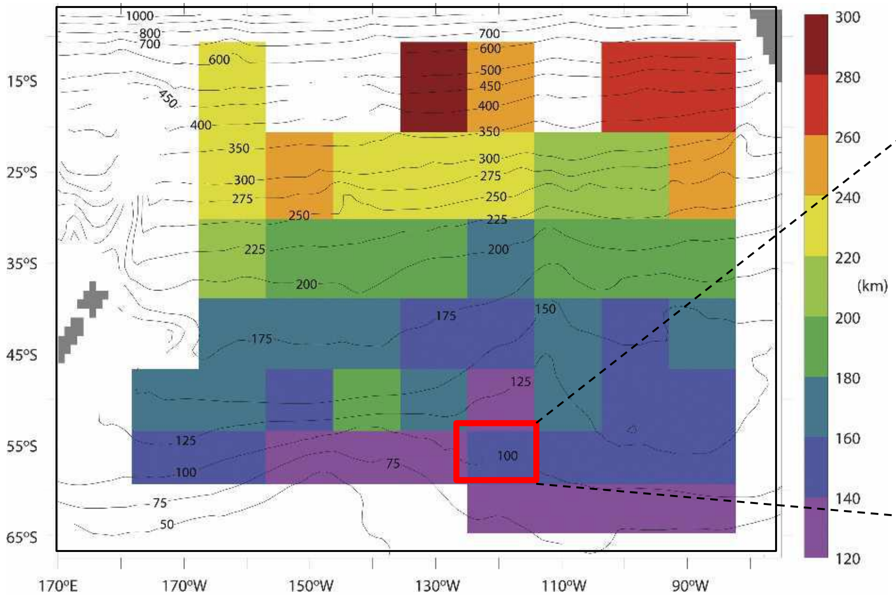
- Forward KE cascade from meso- to smaller-scales is an important pathway for equilibration of global ocean circulation

- Anticyclonic eddies have been observed to shed streamers/filaments more frequently than cyclonic eddies → possible causes include anticyclonic ageostrophic & symmetric instabilities …

- Combined altimeter & surface drifter analysis helps to establish statistics, but difficult to elucidate evolution/mechanism

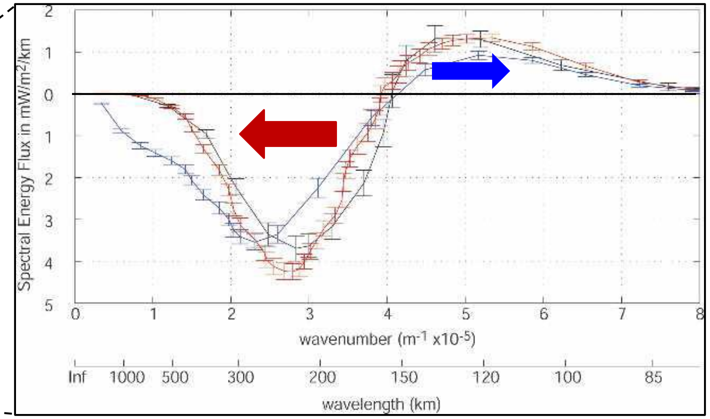
- Analyses of SSH signals that resolve meso- & smaller-scales *simultaneously* can lead to improved understanding of forward KE cascade

Impact of fine-scale variability to meso-scales



Horizontal scale where inverse KE cascade starts

Scott & Wang (2005)

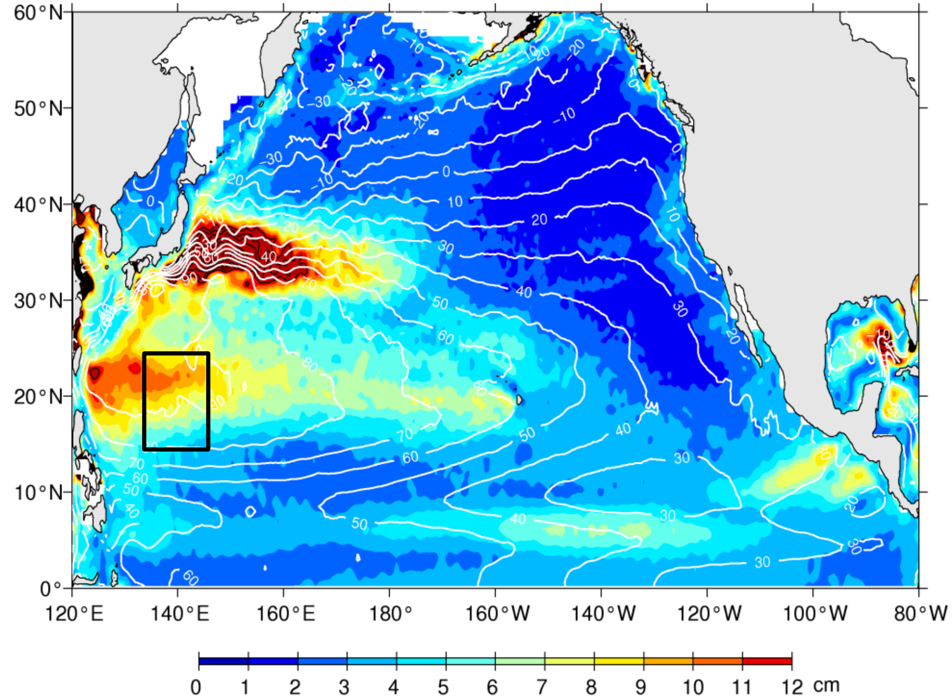


Spectral KE flux *Π* as a function of K_h

- Using AVISO product, Scott & Wang (2005) detected inverse KE cascade in the surface ocean, rather than mediated via barotropic mode; the threshold wavelength where inverse cascade emerges is estimated to be > O(150~250km)

- Subsequent investigations based on both AVISO & high-resolution OGCM output suggest the AVISO-based threshold wavelength is likely over-estimated & the large forward cascade *Π* value could be an artifact of the gridded AVISO product (e.g., Arbic et al. 2013; Qiu et al. 2014)

AVISO rms SSH map in the North Pacific

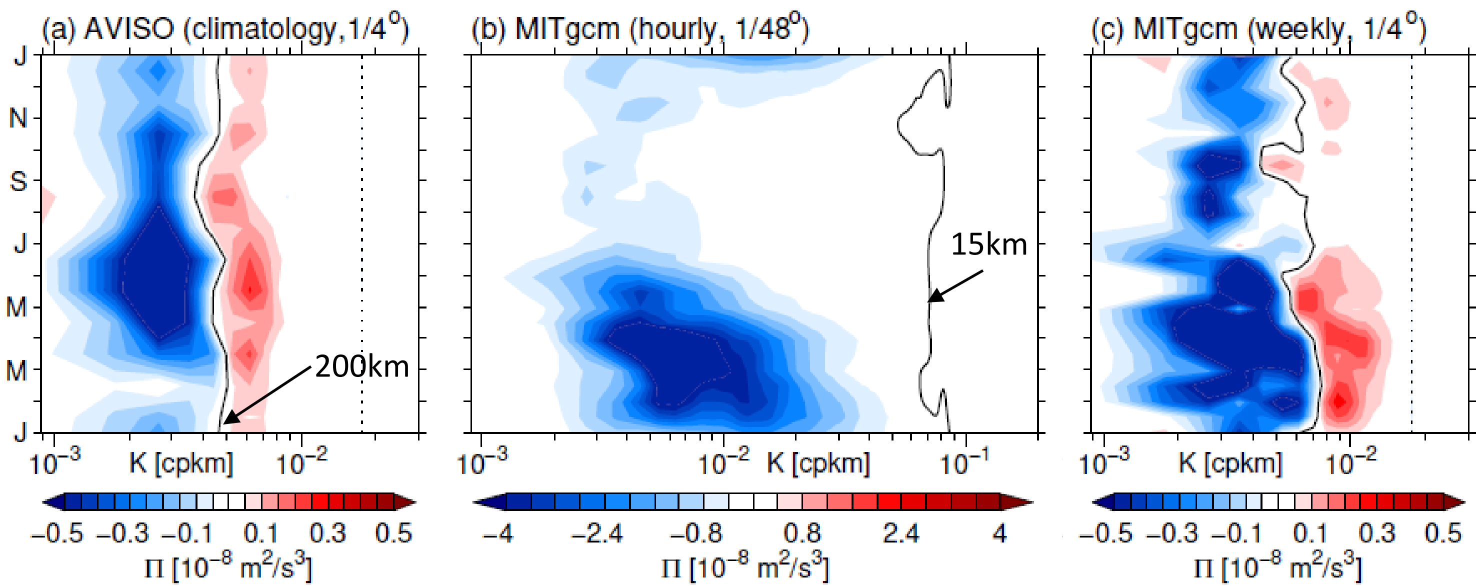


Comments

- Inverse KE cascade likely occurs over the broad 15–150km range of our interest

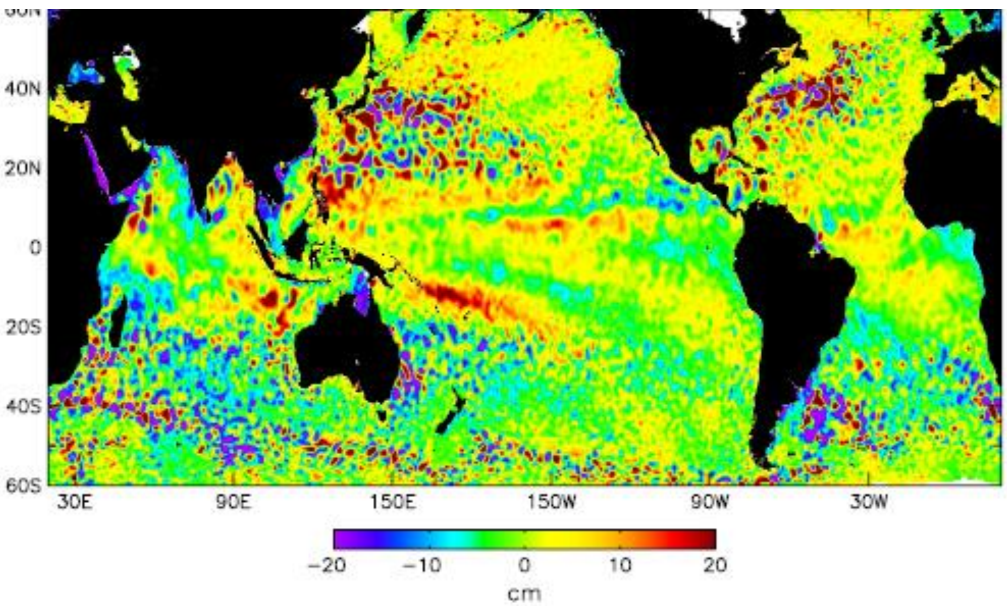
- Need observational fine-scale SSH data to determine the "true" threshold wavelength

- Need to quantify the relative contributions from inverse cascade vs. generation by instabilities for the observed mesoscale EKE field



Π calculated from MITgcm SSH sampled on AVISO grid

Contribution to w by fine-scale upper ocean variability

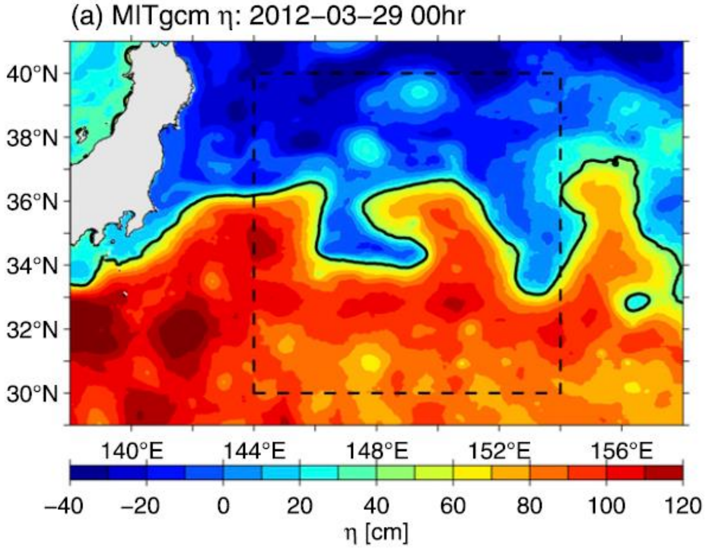


Chelton et al. (2011)

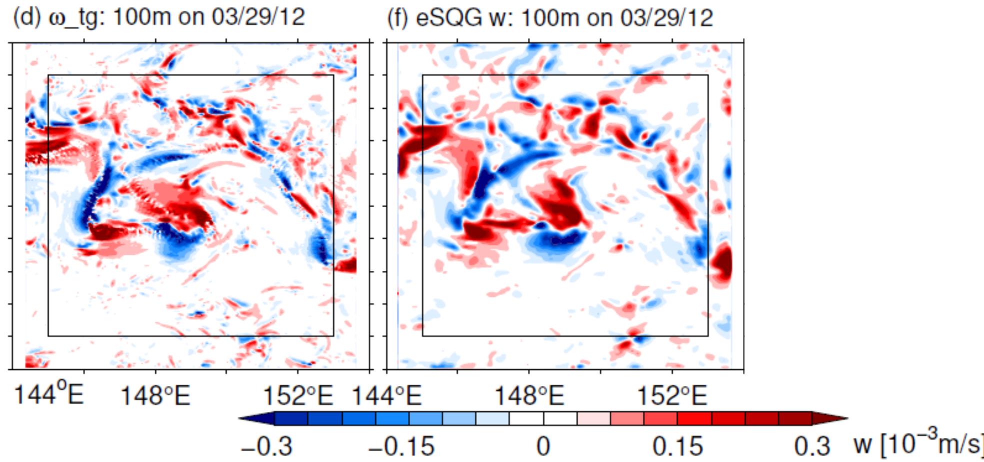
- It is well established that mesoscale eddies play a determinant role in lateral transport of upper ocean mass, heat/salt, & BGC tracers

- Upper ocean vertical circulation, on the other hand, requires divergent motions → finer-scale circulation variability can potentially play a fundamental role as it is less constrained by geostrophy than mesoscales

- In many parts of the world ocean where SQG dynamics dominate (e.g., WBCs, ACC), SSH signals in the 15–150km range can be used to better reconstruct the upper ocean **w** field by using the SQG, or extended SQG, framework (Qiu et al. 2020, JPO)



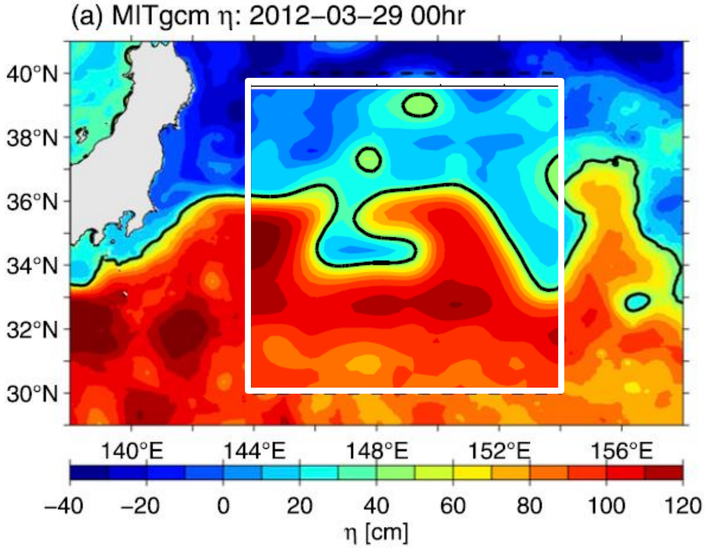
Input SSH data from 1/48° MITgcm



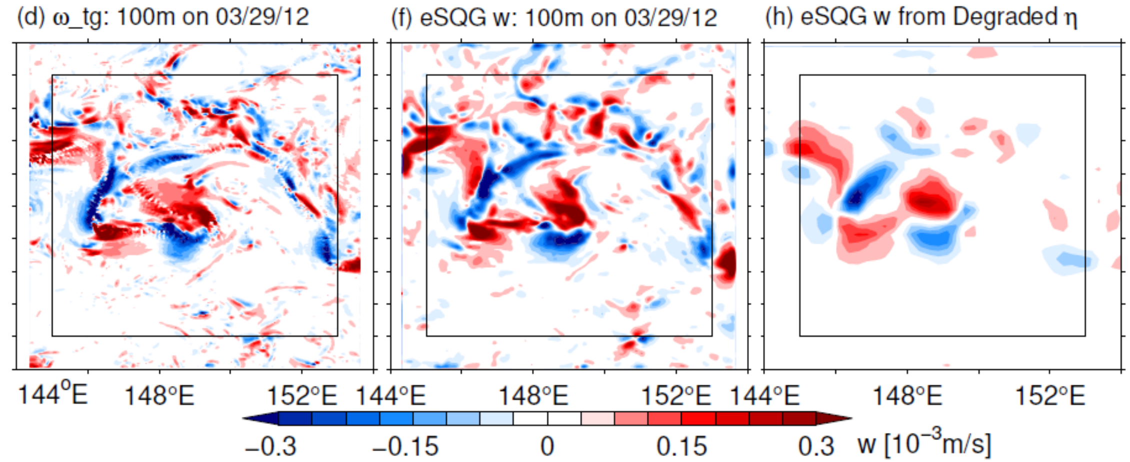
Target balanced w from MITgcm

eSQG-reconstructed w

- Used Lapeyre & Klein's (2006) eSQG formulation; while missing features < O(20km), the eSQG-reconstruction captures well balanced **w** field: spatial correlation r = 0.72



Input SSH data of AVISO-resolution *mesoscale* SSH



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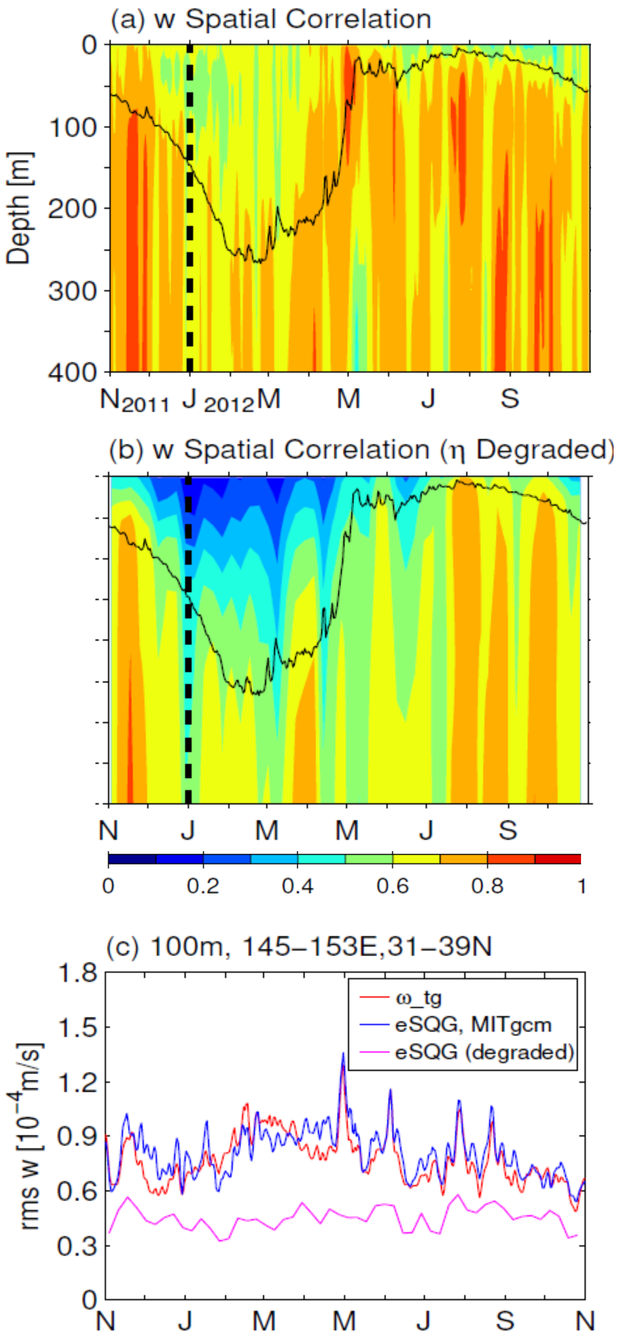
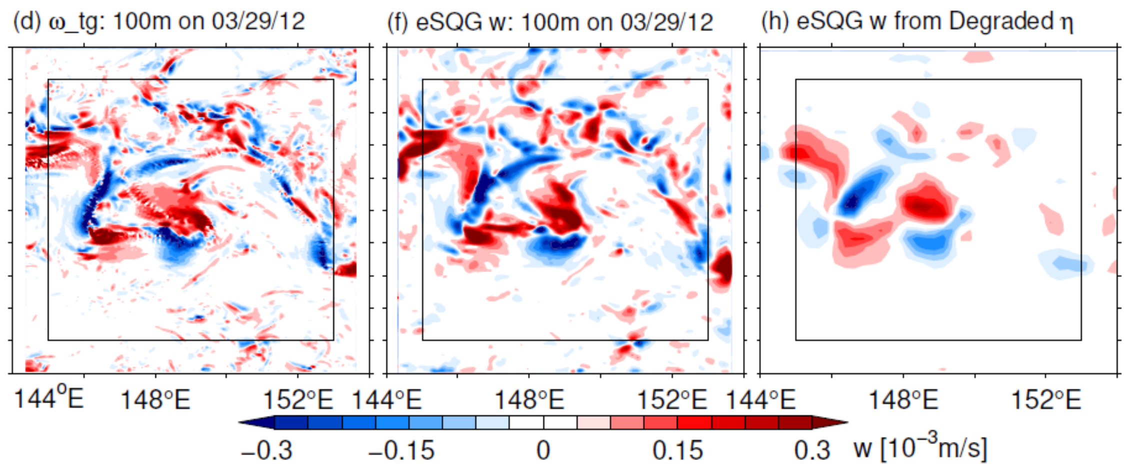
- By degrading input SSH data to AVISO-resolution, only large mesoscale **w** features are now captured; r = 0.51





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- In addition to lower spatial correlations, reconstructed **w** variance is also reduced by 30% in summer & 50% in winter

Concluding Remarks

- Oceanic variability in the 15–150km range play important roles in upper ocean's turbulent KE transfers & vertical heat/material transport
- 15–150km is the range where balanced circulation variability & unbalanced internal tides/IGWs co-exist. Effort to disentangle these 2 types of motions is needed to better describe the smaller-scale balanced flows, including w.
- Fully understanding of the 15–150km oceanic variability requires a synergy to combine analyses of available/forthcoming along-track & along-swath SSH data, HR OGCM simulations & assimilative model output